MASTER

XVIII

ON THE "GROWING SEASON"

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Botanists have long attempted to relate the facts of plant distribution to the facts of climate, and the idea of a "growing season" linked to an annual temperature curve appeared as a natural first step. Over the years no quantitative relationship between "growing season" as defined below and plant activity has been revealed, nevertheless the idea still retains its place in the literature and continues to serve as an initial, although crude, aid in the summarising and classifying of ecological data. It should be noted that a number of investigators prefer to use soil rather than air temperature as the climatic parameter, and in relation to germination and the onset of growth, this would appear to be a reasonable procedure. However in this present paper daily mean air temperature in the standard screen will be the parameter discussed.

Apart from any use which the concept may have to biologists, climatologists may care to note its possible use as a climatic discriminant.

Definition of the "Growing Season"

Two decisions are necessary - the first as to the temperature to be taken as the base, threshold or reference level below which growth is assumed to be negligible, and the second as to whether the length of the "season" should be assessed from long period mean annual curves of temperature, or from the average value obtained from various temperature curves for the individual years (these latter being constructed either from daily values, or from weekly or monthly mean values).

The usual practice in the British Isles is to use 42°F. as the base temperature; some workers however adopt 43°F and yet others (e.g. Andersen and Fairbairn 1955) 45°F. In Germany 5°C (c. 41°F) is used, and values are published employing a second level at 10°C. (e.g. Berlin 1939). In the U.S.A. the period of the year during which mean daily air temperature exceeds 43°F. is usually called the "vegetative period" whilst the term "growing season" is given to the period between the last "killing frost" of spring and the first "killing frost" of autumn. (According to C.F. Brooks - see Conrad (1946) - "a killing frost is one which kills the general vegetation at a place", i.e. is biologically defined, but 'in the absence of killable vegetation a temperature of 32°F. in a thermometer shelter' is adopted, although a killing frost may occur with screen temperature much above 32°F.). It should also be noted that a temperature of about 42°F. is also employed in biological studies as a base for calculating "accumulated temperature", for a recent example employing this idea see Winter and Stanhill, (1957). It appears that a temperature of about 5°C. first became extensively used in the early 19th century as a threshold level above which certain important crop plants in the temperate zone began substantial growth; in these investigations both air and soil temperatures have been employed (for further details the reader is referred to Gloyne, 1956).

Turning to the second decision required, we may estimate the length of the "growing season" (number of days with mid-temperature above 42°F.):

(i) from the annual curve of mean temperature constructed from long-period monthly means;

or (ii) from the average of estimates derived from the annual march of the temperature for individual years based on monthly means, regarding the "season" as defined by the upward and downward passage of the curve through 42°F.;

or (iii) from the average period between the first and last occasions of a daily mean of 42°F., in each year;

or (iv) from the period between the dates when the individual daily values pass upwards through 42°F. for the last time in spring or

summer and pass downwards through 42°F. for the first time in the late summer or autumn.

Results from (ii) will differ from those from (i) only if the curves for individual years cross the 42°F level more than once upwards or downwards. Other possibilities will occur to the reader, e.g. one might combine the data with those of the last and first "frosts" (defined by a screen temperature of 32°F. or a rather lower figure 30°F if desired) and derive yet another series of "growing seasons".

Experience in using the data suggest that (iii) and (iv) give rather unrealistic results. At many places in the British Isles a mean daily temperature of 42°F. can readily occur in mid-winter so method (iii) gives no useful information, whilst using method (iv) a single cold day well within any "season" defined on any reasonable practical basis, would sharply reduce its length when estimated graphically. If methods similar to (ii), (iii) or (iv) are used we may find further support for Sir Napier Shaw's advocacy of the week as the most appropriate time unit for much climatological work (Shaw, 1926, 1939).

A comparison of estimates according to the various conventions (i) (ii) and (iv); for different series of years, and for "seasons" whose length is defined by the interval between the "last" and "first" frosts using both 32°F and 30°F, is given below for Eskdalemuir, Dumfriesshire, Scotland (Ht. above M.S.L. 794 ft.). The r e a d y availability of daily temperature data dictated the selection of the 16 years referred to.

Method (i)	1921-50	200 days
(i)(a)	selected 16 years within 1914-1956	195 days
(ii)	1914-1956	205 days
(ii)(a)	selected 16 years	198 days
(iv)	selected 16 years	144 days

Period between "last" and "first" occasions of daily minimum temperature 30°F. (16 years) 146 days.

Period between "last" and "first" occasion of daily minimum temperature 32°F. (16 years) 125 days.

A "population" standard deviation derived from (ii) is 20 days. Unless the contrary is stated results based on method (i) have been employed in the discussion to follow, because it is the most convenient method of using the available material.

Variation of "growing season" with height above Sea-Level

Let abcd (Fig. 1) represent the average annual march of temperature for some place at a moderate height above M.S.L. in the British Isles, then (bc) - the period during which the curve remains above 42°F. - is the "growing season". (as so defined)

Fig.1, Schematic Diagram to show relationship between length of growing season (L, L'..); annual mean temperature (M, M'...) for nearby stations at different heights (H, H'...) above M.S.L. (H'>H).

At higher altitudes the general level of temperature drops giving an annual curve such as a'b'c'd' with a contraction in the growing season to (b'c'). Providing the line T = 42° intersects the annual temperature curve, the length of the growing season L at any place will tend to decrease (increase) with increase (decrease) of height above M.S.L. Since for moderate altitude, at least, mean temperature changes on average at

about 1°F. per 300 ft., L will change relatively uniformly with height, provided T = 42° does not cut the curve near its highest or lowest point - when the rate of change is rapid and not constant. These variations clearly result from the difference between the annual mean temperature at the place, and 42°F. A moment's reflection will show that the amplitude of the curve will also influence the rate of change of L with change in height, and that the greater the amplitude (i.e. the more "continental" the climate of the place in question) the slower will be the rate of change of L and the greater the height interval through which a uniform rate of change will obtain. Over most of the British Isles the mean annual range (i.e. the annual amplitude) is of the order of 20°F., falling rapidly in western and northern coastal areas to about 15° at the coast; thus in general the annual temperature curves for different places in these islands will be more or less parallel; and furthermore these curves will fluctuate about an annual mean temperature which, when reduced to M.S.L. lies between about 46°F and 51°F. In "continental" areas however, the annual variation is of a difrerent order (e.g. c. 70°F. for Winnipeg, Canada). Whilst in the British Isles the variation of L with height will be largely due to differences between annual mean temperature and 42°F., the contrast between the British Isles on the one hand and "continental" areas on the other - in respect of variations in L - will stem from differences in annual amplitude.

Variation of Length of "Growing Season" with Annual Mean Temperature and Annual Amplitude

A clear idea of the variation of growing season with annual mean temperature and annual amplitude may be gleaned from the set of curves indicated schematically in Fig. 2. This has been produced by assuming that the annual curve is single sine wave of amplitude equal to that of the annual fluctuation.

Fig. 2. To illustrate a theoretical relationship between the length of the growing season, the annual semi-amplitude, and the annual mean temperature (base temperature 42°F.)

A diagram suitable for actual use, and for any base temperature may be constructed from the following formulae. If A is the semi-amplitude of the annual curve - in practice half the difference between the mean of the warmest and coldest months - T(m) the mean annual temperature, and T(b) the base temperature (here 42°F.), then

$$L = \left(\frac{1}{2} - \frac{\alpha}{\pi}\right) \times 365 \text{ days}$$
$$\text{where } \sin \alpha = \frac{T(b) - T(m)}{A}$$

Clearly regions such as the British Isles, with A $\simeq$ 10°F. and with annual means in the upper 40's, are amongst those where rapid changes in L may be expected in response to small changes in T(m). In contrast there will be little change with changes in T(m) in (say) central Canada; e.g. at Winnipeg where the annual temperature range is about 70°F., the actual growing season is 174 days (158 from Fig. 2) in spite of a low mean of 34.6°F. In the limiting case of an infinite value of the annual range A, L will be exactly half a year almost irrespective of the level of T(m).

Differences between the actual values of those computed for individual places are given in the penultimate paragraph of the next section.

Place-to-Place Variations of "Growing Season" with height above M.S.L.

To examine this question quantitatively, data from groups of stations are required covering as great a range of height as possible consistent with their being within the same general region. To fulfil both requirements, it was necessary in some cases to use observations covering different periods.

(a) Southern Scotland and North England

Observations from eleven station records were selected (10 in the Southern Uplands of Scotland and one in Northern Pennines) covering the height range of 50 to 1360 ft. above M.S.L. For six stations (Berwick-on-Tweed, Kelso, Edinburgh R.O., Marchmont, Boghall and Eskdalemuir) the period was 1921-50 (Met. Office M.O.M. 571, 1953) and 1856-95 for the remaining five (Inveresk, Wolfelee, The Glen, N. Esk Reservoir, Allenhead) (Buchan 1900).

If data from all eleven stations are "pooled" some adjustment to the earlier series is necessary to allow for the generally accepted upward trend of mean annual temperature in N.W. Europe, in the last 150 years or so. For the area Durham to the Forth Manley (1953) suggests +0.50°F., whilst a correction based on the well-known series for Edinburgh by Mossmann (1896) indicates +1.1°F.

Accepting an adjustment of +1.0°F, the regression of the length (L) of the growing season in days on height (H) above M.S.L. in hundreds of feet is given by

$$L = 245 - 4.0H. \qquad \sigma(L) = 18 \qquad r(L, H) = -0.89$$

where σ (L) is the standard deviation of L and r (L,H) the correlation coefficient between L and H.

Estimates and actual values of L for three other stations in Northern Britain are given below; even for Ben Nevis the computed estimate may be regarded as close bearing in mind that the highest station utilised for the regression was Allenhead (Northumberland) 1360 ft. above M.S.L.

Station	Ht. above M.S.L.	L(computed)	L(actual)	Period
Ben Nevis	4,400	48	0	1884-1903
Gt. Dunfell	2735	134	127	1906-35 (est.Manley 1942)
Moor House (Cumberland)	1840	171	158	1932-35 (Manley, 1936)

(b) North Midlands

A group of eight stations (250 ft. to 1300 ft. above M.S.L.) was selected ranging from Malham Tarn in the North to Buxton in the South. For six of these the full 1921-50 record was available, for one - Bingley - the 10-years 1946-55, and for Malham Tarn only the six years 1950-55. The appropriate statistical relationships are:

$$L = 264 - 4.7\,H \qquad \sigma(L) = 18 \qquad r(L,H) = -0.91$$

(c) West Wales and South Devonshire

Two other sets of data are instructive. Smith (1950) has summarised certain statistics for three west facing stations near Aberystwyth at 12, 452 and 950 ft. above M.S.L.; the appropriate points lie close to the straight line

$$L = 305 - 5.8\,H$$

For three stations in Devonshire (Teignmouth (20 ft.), Newton Abbot (272 ft.) and Princetown (1360 ft.)) the appropriate points also lie close to a straight line

$$L = 365 - 9.0\,H$$

Some of the increase in the coefficient of H from about 4.0 in S. Scotland to 9 in Devon is due to the reduced amplitude in the south west coastal areas but much more important is the fact that, especially in the second case, the base temperature 42°F. is near the lowest point of the curve, and accordingly in the zone of rapid and non-linear change of L - that the points do lie on a straight line must be largely fortuitous. Were we to move from (say) Princetown to a hypothetical plain at 2500 or 3000 ft. further up, the rate of decrease of L would certainly fall to a linear rate of about 5 days per 100 ft.

(d) Switzerland

Conrad (1946) quotes a formula for Switzerland - using base temperature 43°F. - which is equivalent to

$$L = 268 - 2.1H$$

It is interesting to note that were this rate of decrease applicable to the Ben Nevis area at 4400 ft., the growing season would be about 150 days against our estimate of 48, and the actual value of 0.

Fig. 3. Mean Annual Air Temperature for Selected stations.

In Fig. 3 the annual march of temperature for five different places are given. For three of the places the annual means are almost the same viz. 51.4-51.8°F. The importance of annual amplitude in connection with the variation in length of growing season - especially with respect to change in height - will be obvious.

Except for the three Welsh stations and Newton Abbot, the graphical estimate from Fig. 2 exceeds the measured value for all stations analysed in (a) and (b) and (c) of the previous section, generally by less than 10 days, although for the higher stations (except Princetown + 3) the over-estimate is between 15 and 20 days. For a group of nine stations in central Germany, a graphical estimate using two levels for T(b), viz. 41°F. and 50°F., gave overestimates of not more than 6 days. As noted above Winnipeg's underestimate is large viz. 16 days and roughly the same as for Newton Abbot; that for the Welsh stations is 6 days or less.

These anomalies are obviously linked to the error in assuming that a single sine curve adequately represents the seasonal march of temperature at all places. The matter cannot be pursued here, but there are interesting associations with some facts brought out by Craddock (1956) in his harmonic analysis of annual temperature variation.

Year-to-Year Variation in Length of Growing Season at Eskdalemuir

The growing season for each of the years 1914-1956 was measured from an annual curve constructed from the monthly means (Method ii on p. 1). When the curve passed through 42°F. more than twice, a rather arbitrary decision was made as to the effective passage through 42°F. - in general transient periods above 42°F. early or very late in the year were ignored. In order to reduce errors due to asymmetry of distribution of the dates of passing through various temperature thresholds, some workers (e.g. Currie 1957) prefer to use the median rather than the mean date and these statistics are included with others in the following table.

Table 1. Data relating to the year-to-year variability of "Growing Season" at Eskdalemuir, Dumfriesshire. 1914-56.

	Starting Date (D_1)	Finishing Date (D_2)	Length of Season (L)
Mean	13th April	4th November	205
Median	16th April	31st October	202
Earliest	3rd March	14th October	174 (shortest)
Latest	4th May	26th November	266 (longest)
Standard Deviation	15	11	20

Regression of L on D_1

$$L = 319 - 1.1.D_1 \qquad r(L,D_1) = -0.83$$

There is little relationship between D_1 and D_2, and most of the variation in L from year to year is due to variations in the starting date D_1, - the date of the end of the season being more stable. Incidentally two statistical tests failed to reveal any significant tendency for persistence or alternation between successive years.

Some tentative conclusions relating to the significance of "Growing Season"

In connection with the variability mentioned above, one's general impression is that, in actual farming experience, years will differ from each other more in the extent to which the "season" continues into the autumn, than in year-to-year variations in starting date. This suggests that the range of plants for which this present discussion might be valid are unable to take advantage of early starts to the season, or equally probably find early growth arrested by frost. It is relevant to bear in mind the implication of Smith's (1954) figures in which he shows that at Rothamsted (Herts.) the date of the first autumn frost is more stable than that of the last spring frost; on the other hand a quick scrutiny of data from some Scottish stations did not confirm Smith's conclusion as a general rule, especially on the coast.

I am indebted to Professor S.H. Beaver (Un. Coll. N. Staffs.) for the comment that a growing season of about 200 days or more should be ample for most commercial crops. Nevertheless an extended period could be agriculturally useful, in permitting either the cultivation of more than one crop per annum on the same land, or probably more important, a longer grazing season.

For a more detailed consideration of the agricultural and land-use implications of the matters discussed above, the reader might well start by considering certain facts described by Manley (e.g. 1952) who was one of the first to draw attention to the rapid rate of deterioration of climate with altitude in the British Isles compared with many other countries. Similar matters are also discussed in "Weather and the Land" (1955). Whatever physical mechanism may be at work, it is a fact of observation and extensive experience that a markedly less favourable environment for most activities, notably agriculture, occurs as one mounts a few hundred feet, even from the genial sea-level climate of South Devonshire.

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October 1958.

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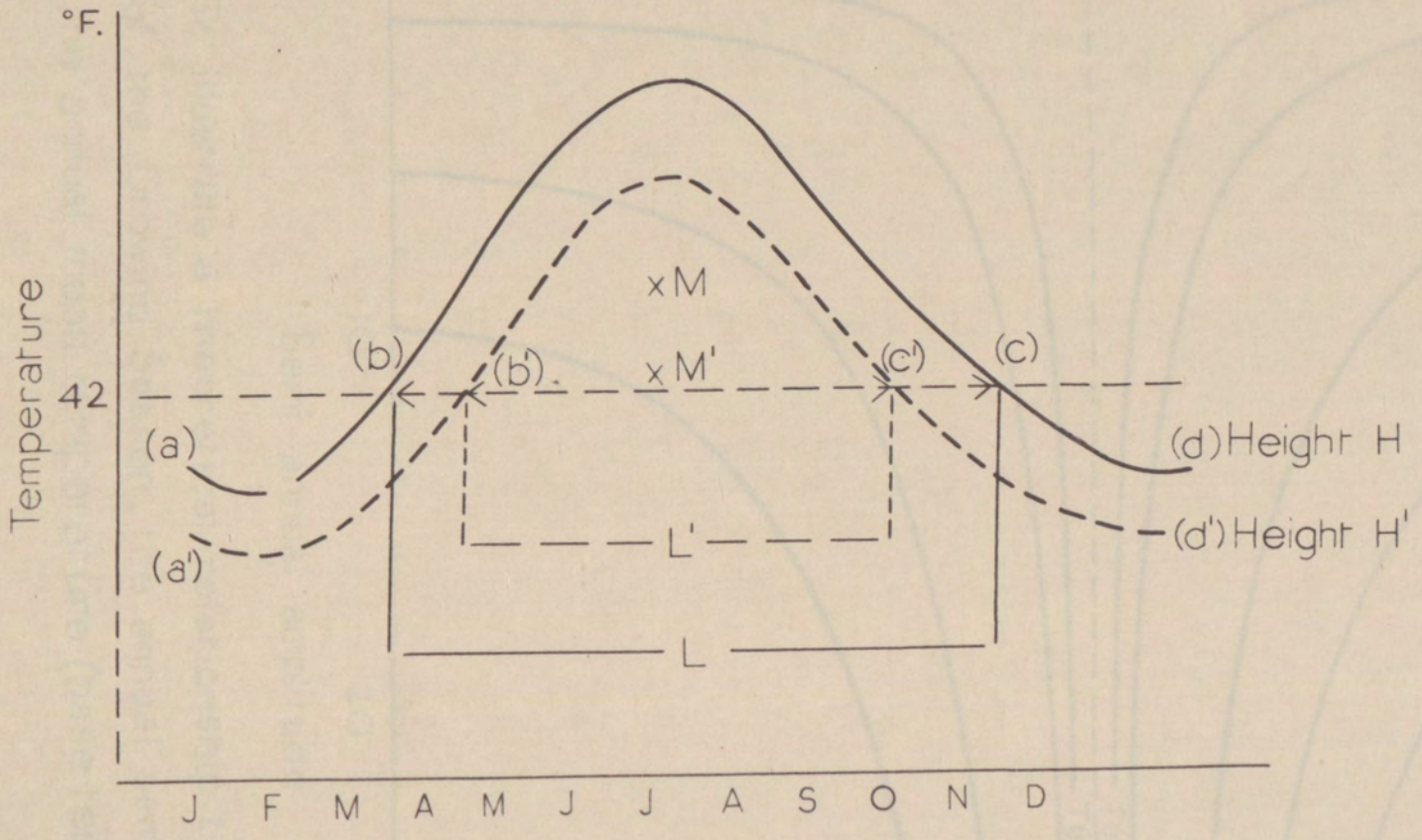

Fig I. Schematic diagram to show relationship between length of Growing Season (L, L'--), annual mean temperature (M, M',--) for nearby stations at different heights (H, H'--) above M.S.L (H' > H)

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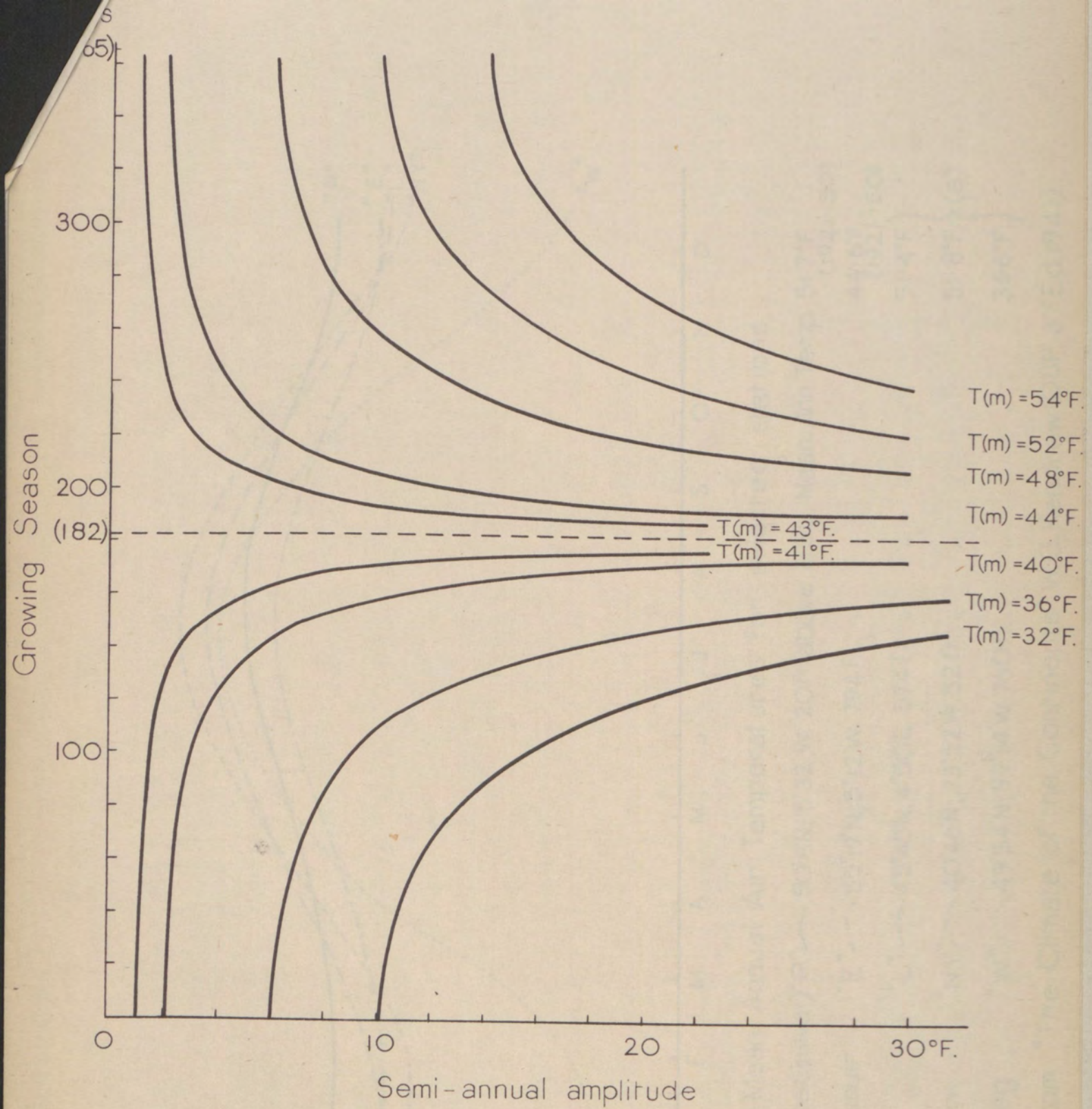

Fig. 2 To illustrate a theoretical relationship between the length of the Growing Season, the annual semi-amplitude, and the annual mean temperature (base temperature 42°F.)

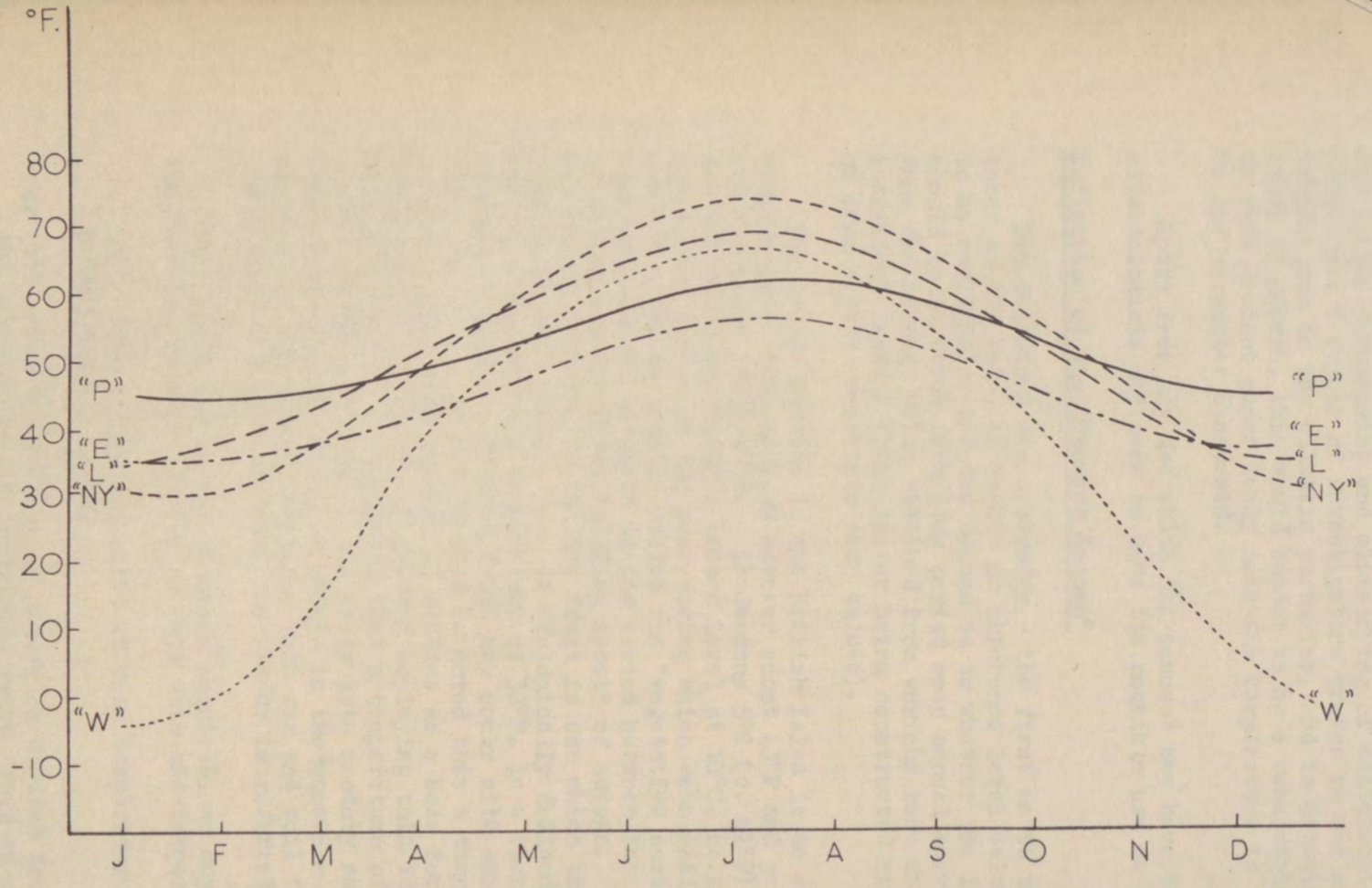

Fig 3. Mean Annual Air Temperatures for selected stations

Penzance (Gulval)	"P"	50°8'N; 5°32'W. 20ft above M.S.L.	Mean. Ann. Temp (1921-50)	51·7°F.
Eskdalemuir	"E"	55°19'N.; 5°12'W. 794ft.	" " " (1921-50)	44·6°F.
Lyons	"L"	45°45'N; 4°50'E 574 ft.	" " "	51·4°F. (a)
New York	"NY"	40°46'N; 73°52'W 52 ft.	" " "	51·8°F. (a)
Winnepeg	"W"	49°54'N; 97°14'W 760ft...	" " "	34·6°F. (a)

(a) From "The Climate of the Continents" W.G. Kendrew (O.U.P. 3rd Ed, 1941)

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